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ATHODYD FIELD TEST NO. 1

TC Report CME-25

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February, 1945

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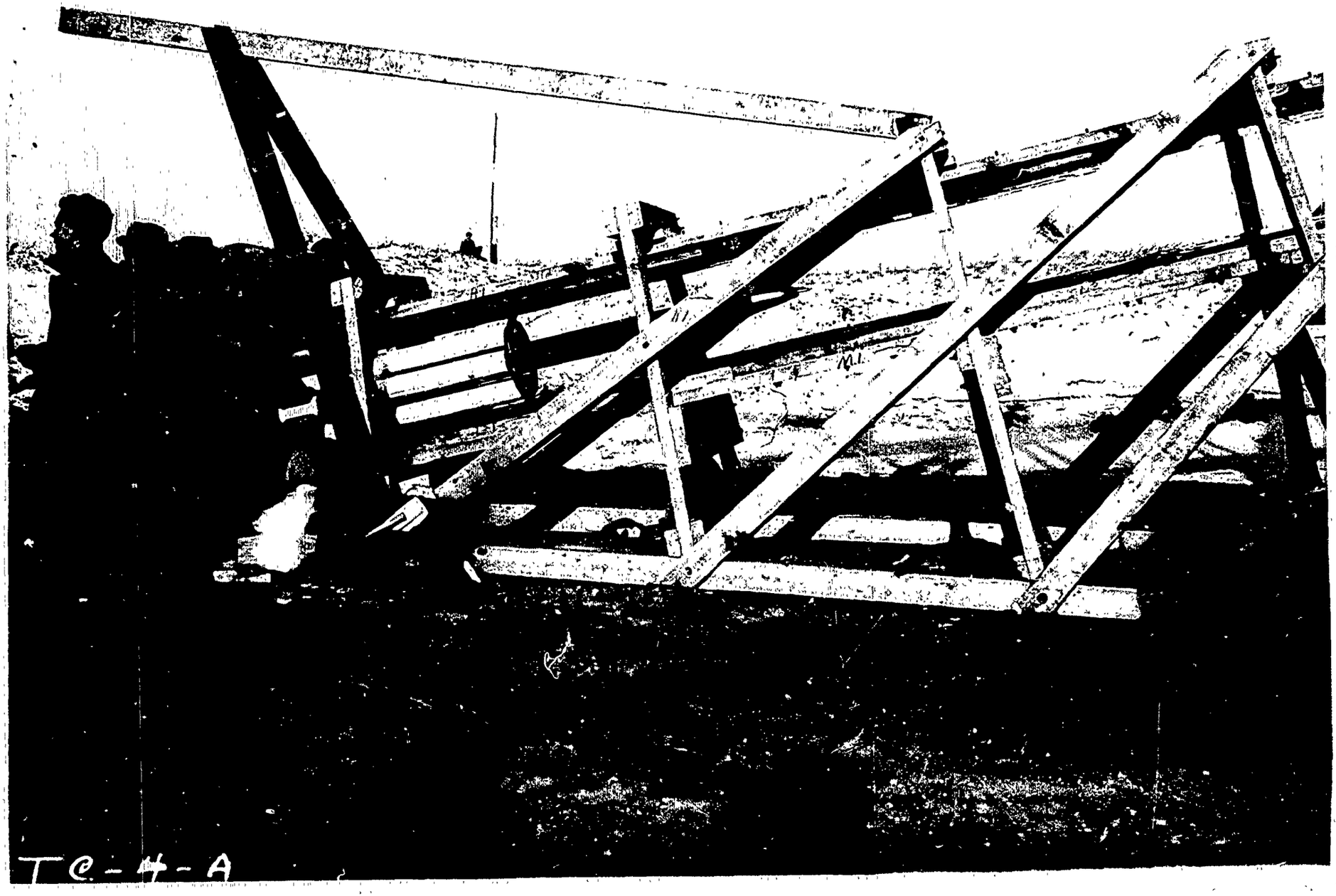
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I.

ATHODYD FIELD TEST NO. 1

This is the first report of a series of flight studies to be made on athodyds.

These units are not regarded as prototypes of a complete Bumblebee, but are designed primarily to give data on propulsion and drag at supersonic speeds.

SUMMARY. -- This test involved:

(a) A trial of procedure for launching an athodyd by use of four 5" HVAR rocket motors. Speed exceeding 1500 ft/sec was obtained, and launching was satisfactory in all respects.

(b) A determination of supersonic drag for a dummy athodyd. A drag coefficient was found to be 0.5 in reasonable agreement with expectations.

Appendix I gives a summary of numerical data. The firing, which took place at Island Beach, New Jersey, involved two rounds on February 16 and three rounds on February 18.

DESCRIPTION OF MODEL. -- The dummy athodyd, which will be referred to the "bird", under test has been designated as Model 1D and comprises a central body mounted in the front end of an 8 ft. length of 6 in. stainless steel tubing. The forward ogive of the central body has a 1/4 caliber radius and projects ahead of the annular intake duct. The tapered rear end of the central body is within the duct, forming a diffuser of 1:4 area ratio. A constriction at the rear produces an exit area approximately equal to that at the intake. Four 3 in x 6 in fins are attached externally to the tube at the rear.

LAUNCHING FACILITIES. -- Launching is accomplished with a launching carriage*, as will be clear from the photograph appearing as the frontispiece to this report. The carriage is a rigid assembly of four 5-in HVAR rocket motors (Navy designation Mark 2 Mod 3 Motor), closed at the front by non-streamlined caps interconnected by 1.25-in manifold tubing. The bird is placed in the center, receiving thrust from a plate at the rear, against which it rests. Centering of the bird at the forward end of the carriage is maintained by four small and easily displaced

* Details of the launching carriage and of the bird are shown in APL drawings G-20105-0, (this furnishes information on weights and centers of gravity) F-20104-0, D-20096-0, D-20093-1; and drawings F-20038-0 and E-20039 cover the launching ramp. Copies of these drawings may be obtained upon request.

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wooden wedges. In flight, when rocket burning is completed, the carriage readily disengages the bird and falls behind because of greater drag deceleration.

The launching ramp* has an elevation of 15° and a length of 30 ft. Two parallel rails in a vertical plane engage four shoes attached to the carriage assembly.

INSTRUMENTATION. -- Fig. IX shows the location of observing stations. The following facilities were employed to observe the flights:

1. A tracking system in which all records are taken by synchronously driven motion-picture cameras. Correlation among cameras is secured by means of light flashes. Mark 51 director stands are located at Central Station (A) and South Station (C). Both are used for visual tracking and carry tracking cameras. The stand at Central Station also carries the dish for a Mark 26 radar located there. Cameras record train and elevation for both stands and the radar range-scope indications. This system was in full operation only on February 18.

2. Two K-25 wide-angle aerial cameras. These were located at Midway Station (B), where they have a side view of the first few thousand feet of trajectory.

3. Continuous-wave radar equipment. On February 18 a party from the Ballistics Research Laboratory (Aberdeen Proving Ground) provided CW (continuous wave) radar equipment and made measurements of velocity from a position behind the ramp at Central Station. Results and a description of the method are given in reference (2).

4. Deceleration sondes. -- Two types were used: one furnished by the Princeton Group and one by the TC-M group at APL. References (3) and (4) contain descriptions of these devices and results of their performance.

5. Other instruments. -- Alidades were used at South and Far South (D) Stations to obtain bearings of splashes. Stopwatch times of flight were also taken.

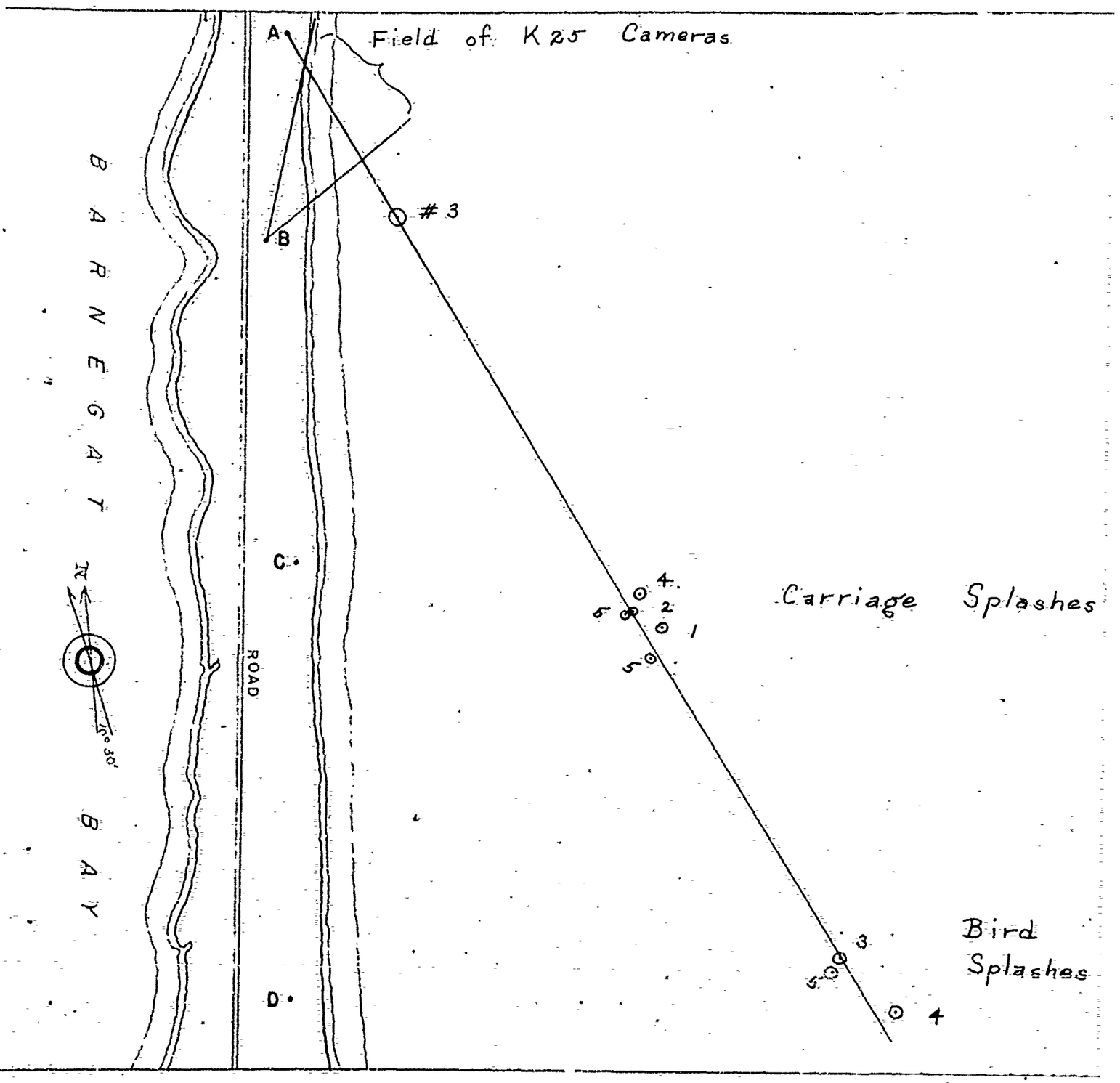
Preparations for this tests were made under severe time limitations. Although adequate data were secured, the full technical possibilities of the observing techniques were not in general realized. The data which were actually secured and used are listed in Appendix II.

ISLAND BEACH TEST AREA

Fig. IX - Test #1

LEGEND

A CENTRAL STATION
B MIDWAY STATION
C SOUTH STATION
D FAR SOUTH STATION



SCALE
1" = 2000'

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LAUNCHING. -- The overall performance of the launching ramp and carriage was uniform and entirely satisfactory. Flight of the carriage assembly was stable, and separation occurred promptly and reproducibly.

The most detailed record of the early flight of the carriage was secured from the CW radar data. The Aberdeen group, which made an analysis of these data, furnished a very large number of points from which the velocity-time curve in Fig. I was derived by smoothing. The CW record was abnormally disturbed and discontinuous for reasons not now known. As a result, the individual determinations of velocity were based on counts usually of not more than 10 or 20 Doppler cycles. These yielded some obviously spurious points, but in the main blocked out a smooth curve with about 3% scatter. Except for the divergence shown in curve b of Fig. I, no differences greater than the experimental uncertainties appeared between rounds. The peak velocity of 1530 ft/sec was unfortunately one of the least well defined points on the curve, but this maximum agrees well with prediction (reference (5)).

Fig. II shows acceleration during burning, derived from the CW velocities. The very early portion of the velocity curve (below 300 ft/sec) was not observed, nor was the instant of firing recorded on the CW record. To fix a time origin the early acceleration was assumed constant, and the velocity curve extrapolated linearly to zero.

The only irregularity noted in the launchings was on round #3, in which the four rocket motors broke apart in flight. The break-up, which was observed visually and in the 12-in tracking camera at Central Station, occurred after separation from the bird, which showed normal flight. Figs. V and VI, which show observed motion of the four parts, suggest that one motor dropped off somewhat before 3 seconds, and that the remaining three separated just after 3 seconds. Curve b of Fig. I shows abnormal flight of this carriage between 1.5 and 3 seconds.

SUPERSONIC DRAG. -- It was not found possible to distinguish separate velocities for bird and carriage in the CW radar record. The descending portions of curves a and b of Fig. I are ascribed to the carriage both because it is the nearer and larger target and because of the high indicated drag. Fig. III shows deceleration of the carriage after the completion of burning for the two normal rounds recorded. Corresponding drag and deceleration coefficients appear in Appendix I.

A record of supersonic flight of the bird has been derived from the wide-angle photographs from the K-25 cameras, showing relative positions of bird and carriage with considerable precision. These data, taken in combination with the CW record for the carriage, give a reasonably well-defined deceleration for the bird for its first 0.7 second of free flight. Fig. IV shows all photographed separations; all five rounds are represented. The points conform well to a single curve,

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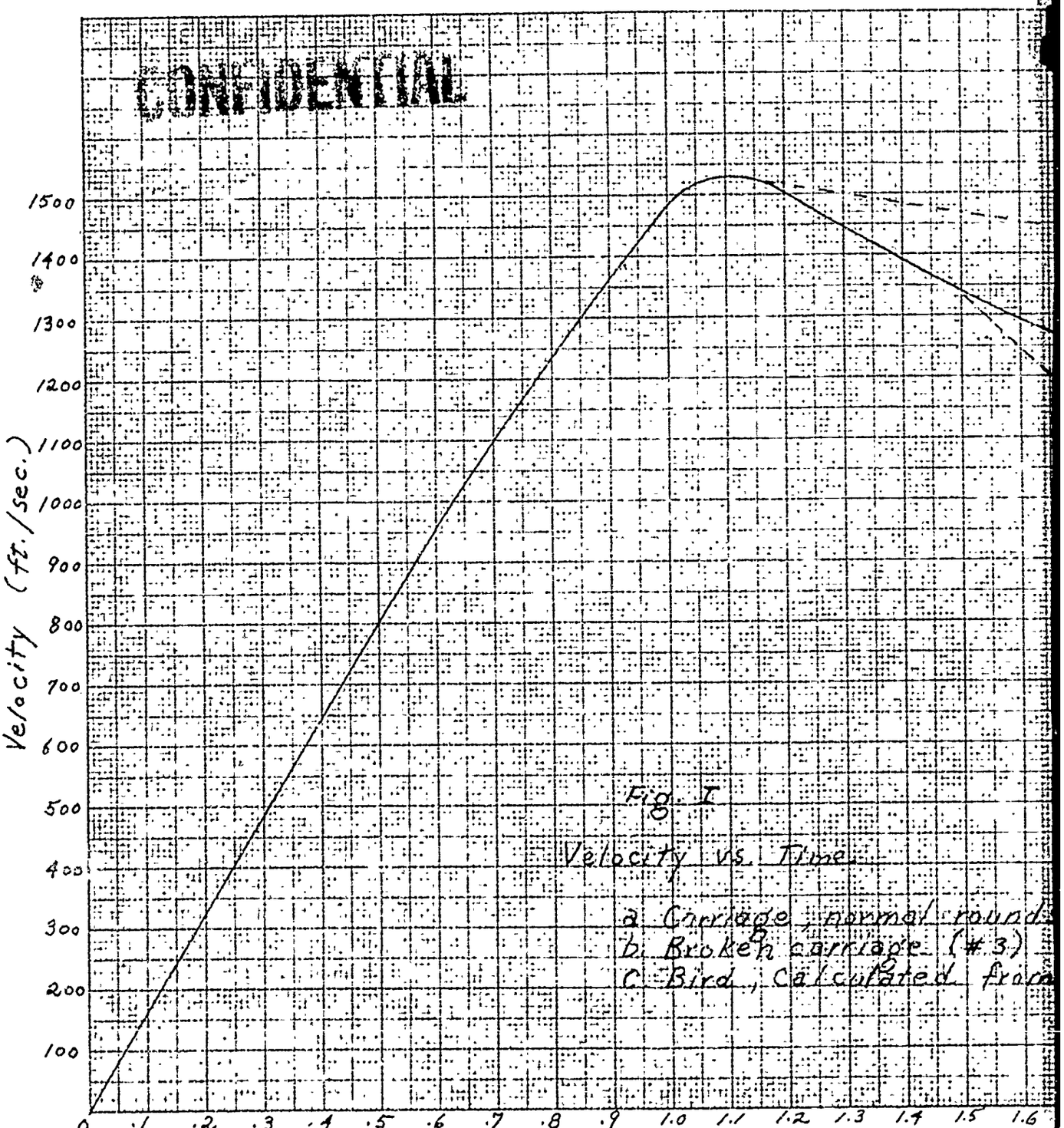


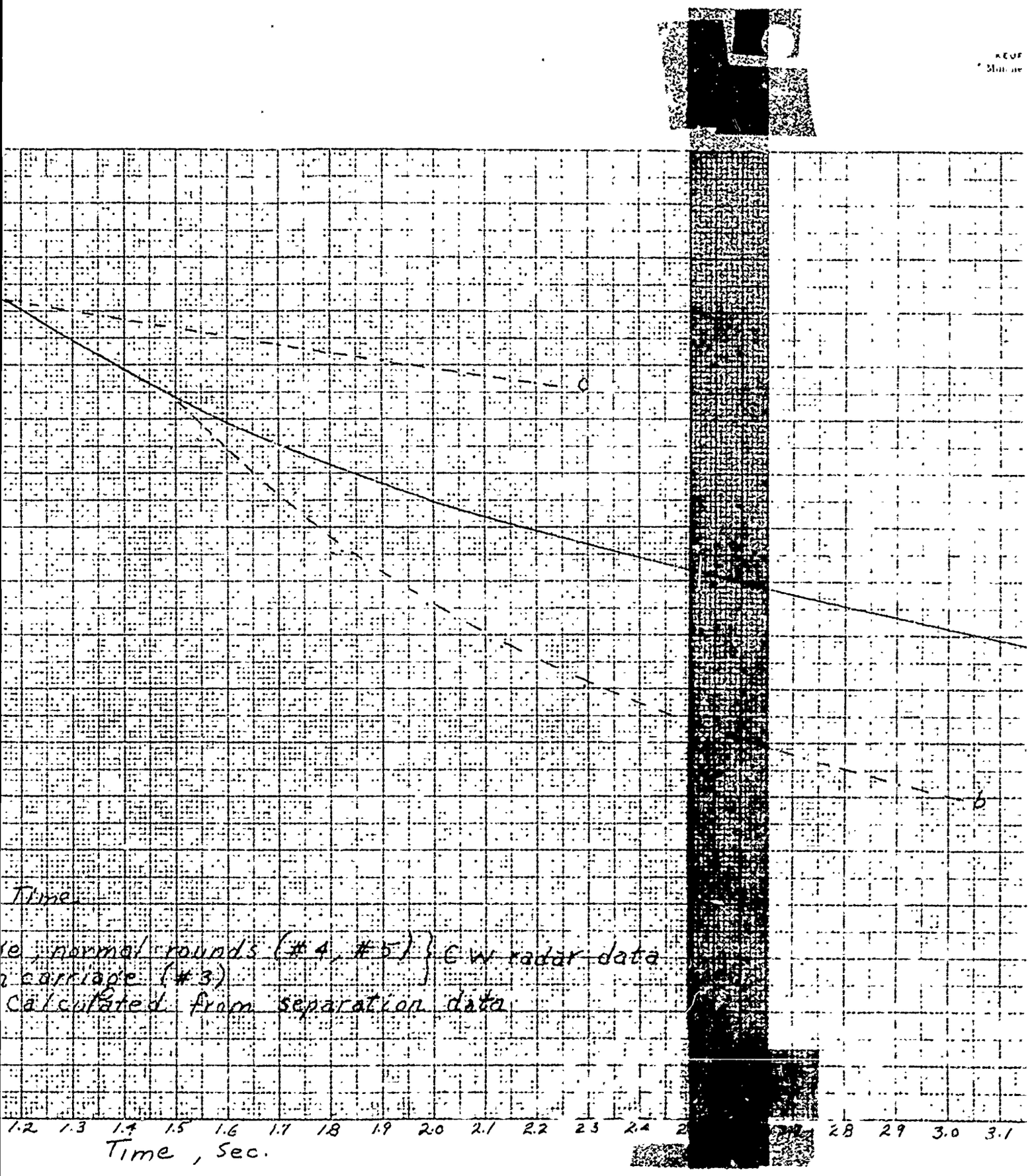
Fig. I

Velocity vs. Time

a Carriage, normal round

b. Broken carriage (#3)

C Bird, Calculated from


Time
e, normal rounds (#4, #5) } C w radar data
carriage (#3)
Calculated from separation data
1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.8 2.9 3.0 3.1
Time, Sec.

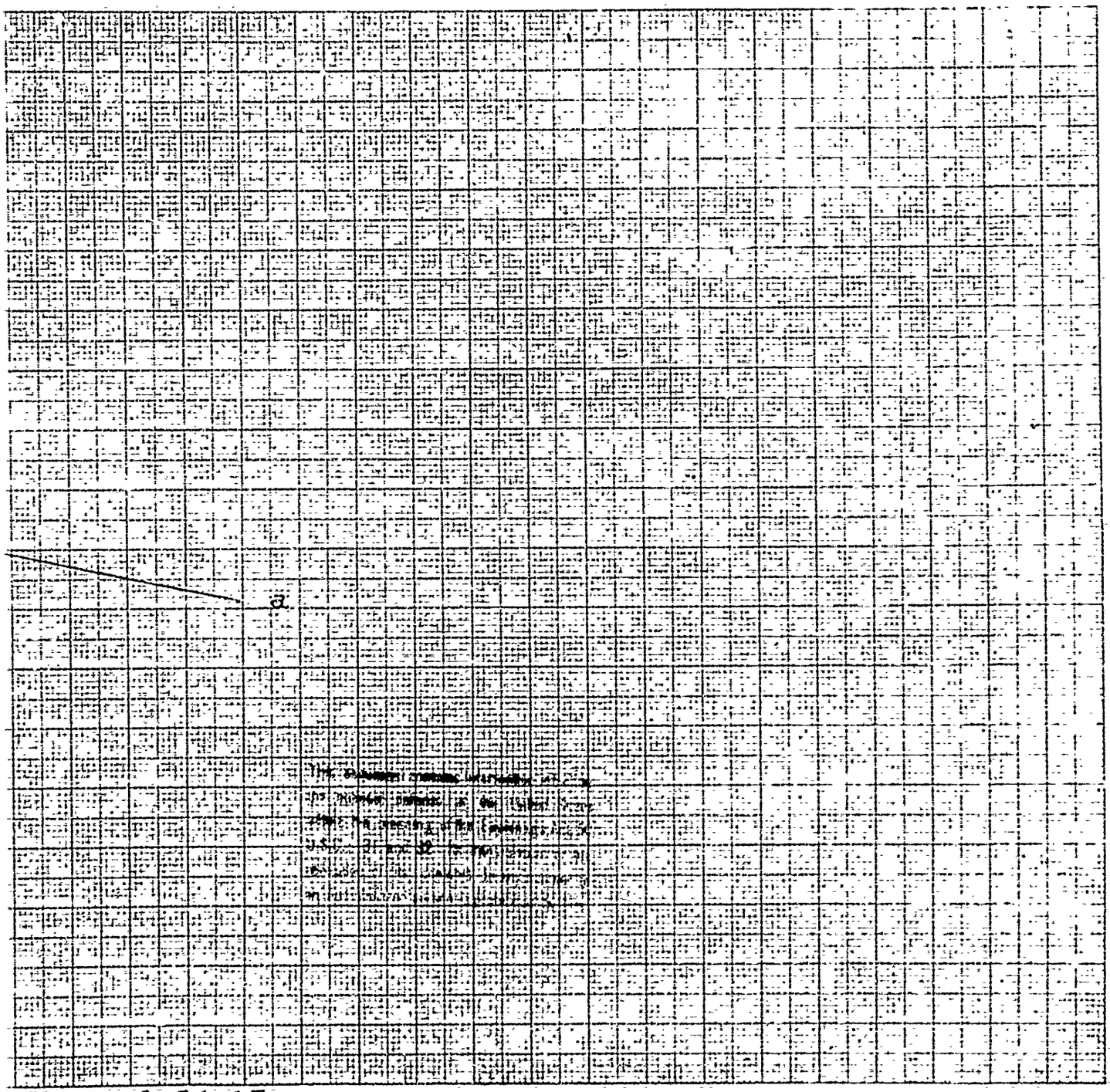


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Fig II Acceleration during burning
(Slope of curve a, Fig I)

——— Based on observations
- - - - Fixed by choice of time origin

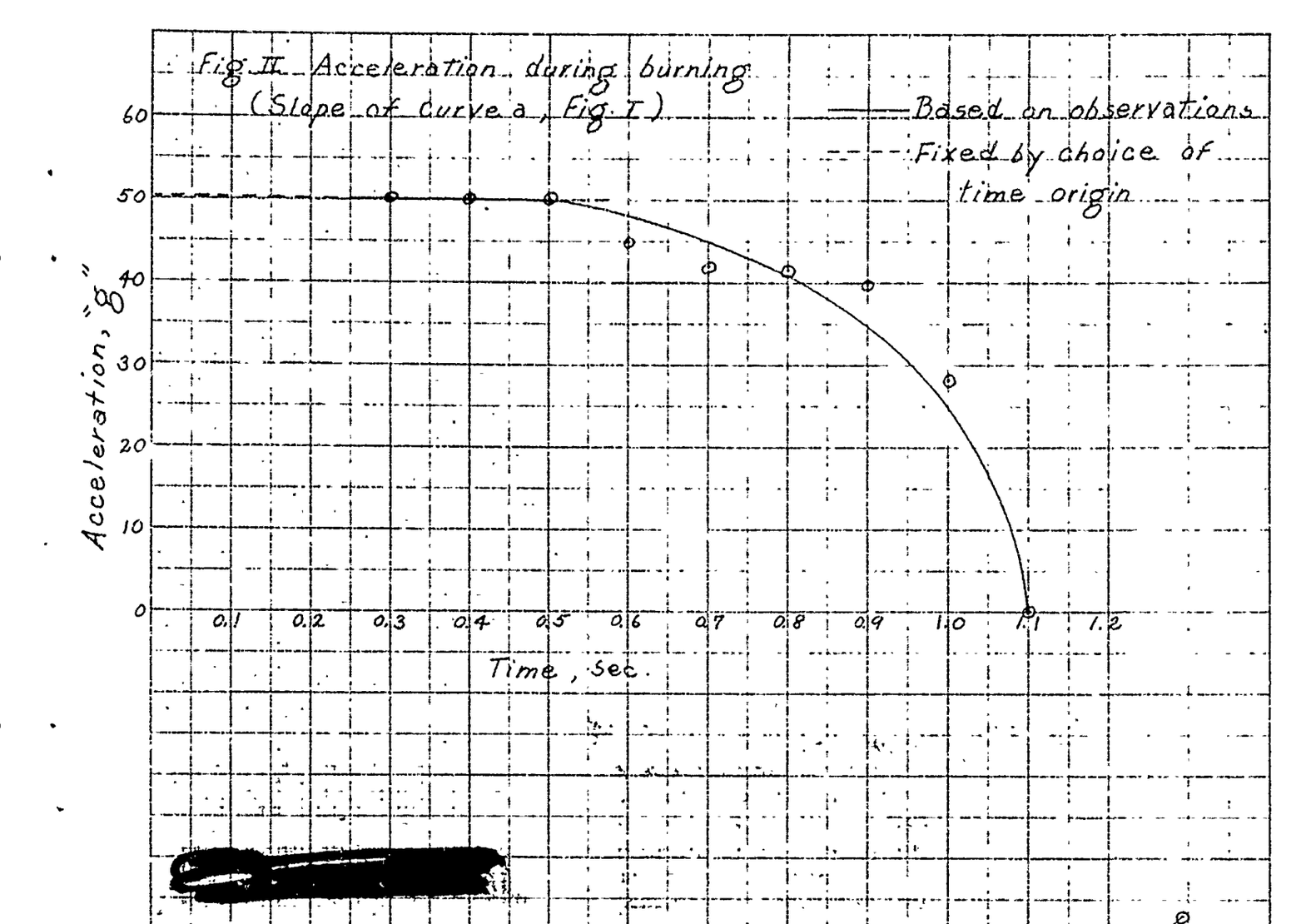
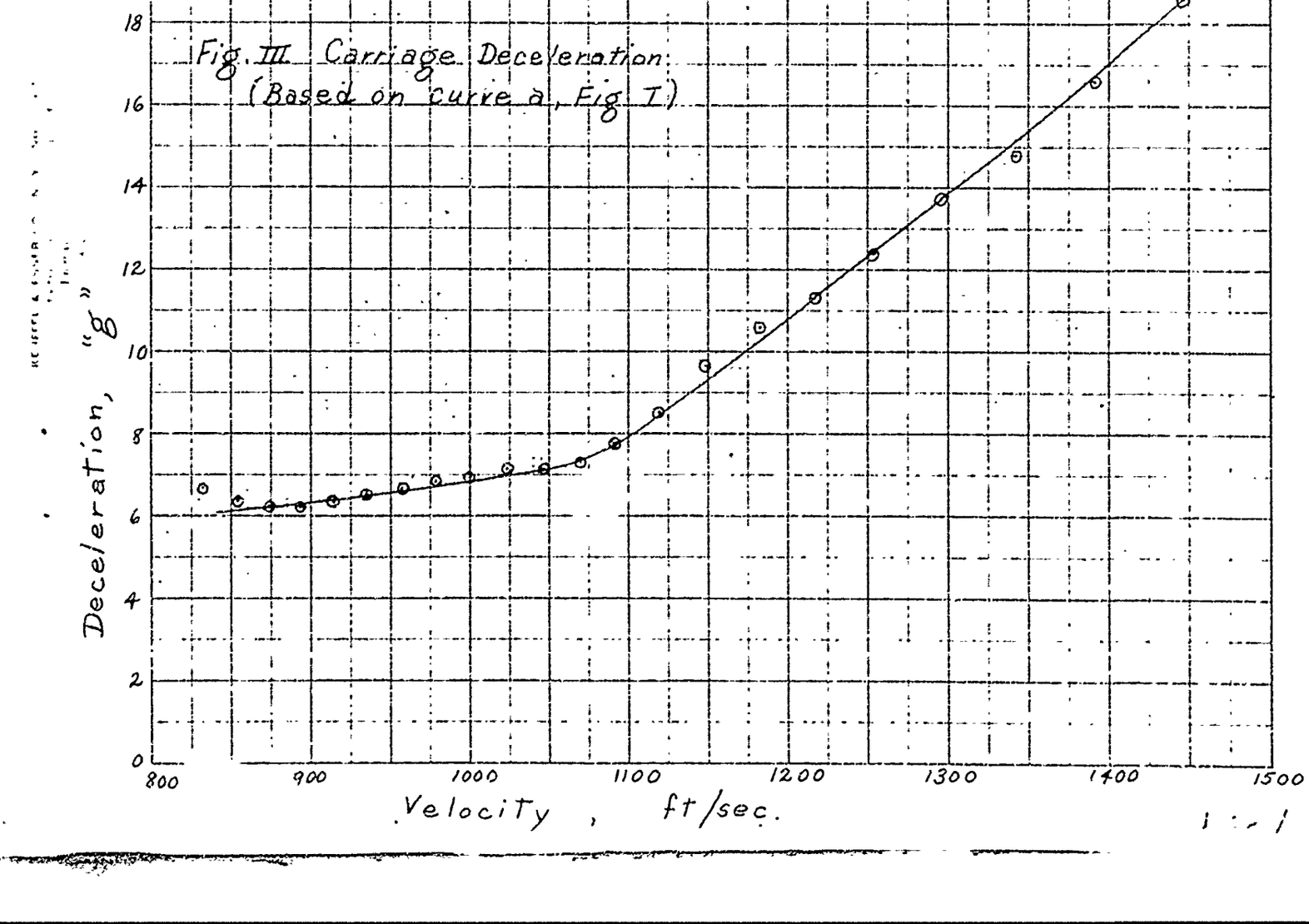


Fig III Carriage Deceleration
(Based on curve a, Fig I)



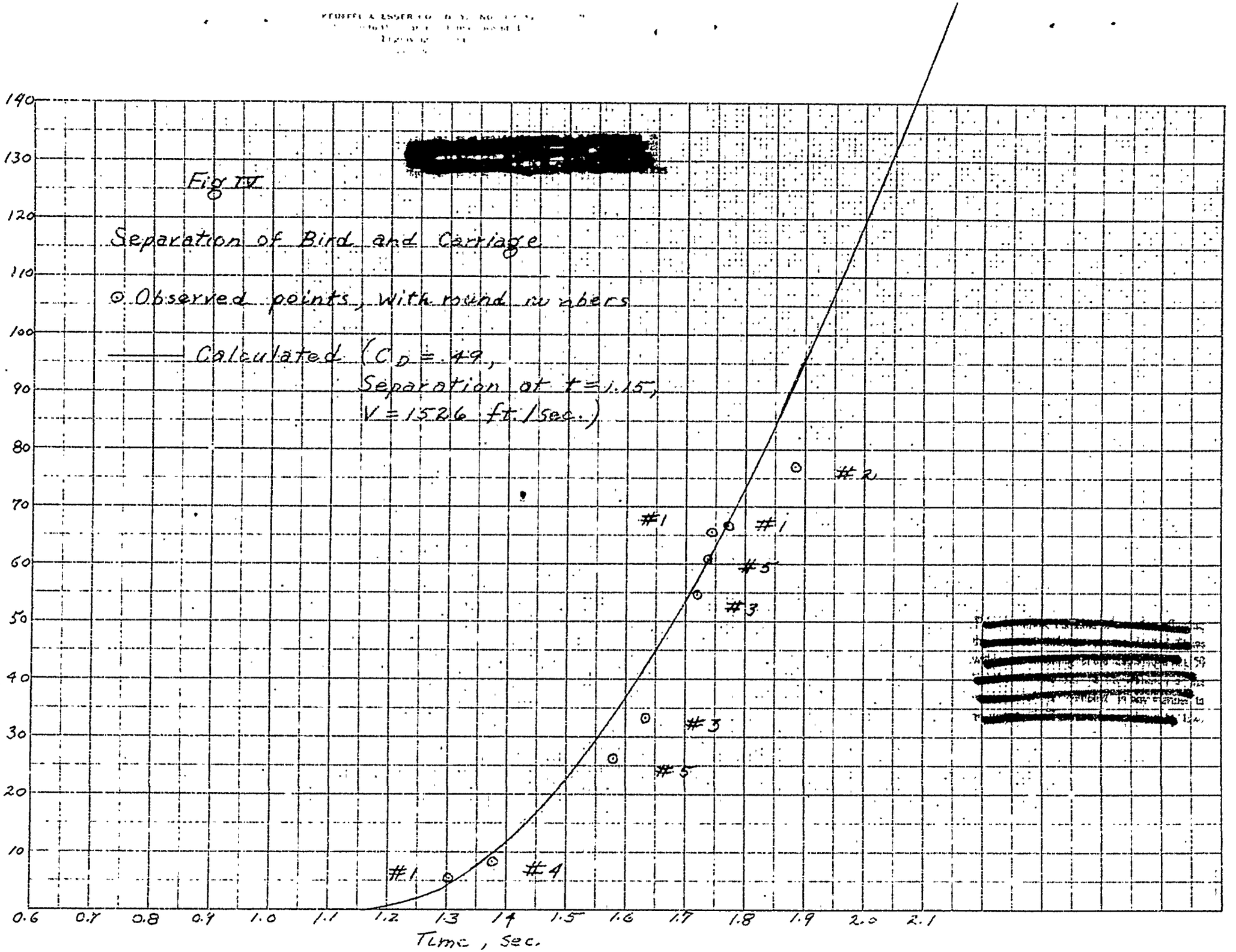


Fig IV
Separation of Bird and Carriage
⊙ Observed points, with round numbers
—— Calculated ($C_D = .49$, Separation at $t = 1.15$, $V = 15.26$ ft./sec.)
#1
#2
#3
#4
#5
Separation, ft.
Time, sec.
10
20
30
40
50
60
70
80
90
100
110
120
130
140
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1

Fig VI Carriage parts, Round 3. Motion in Elevation

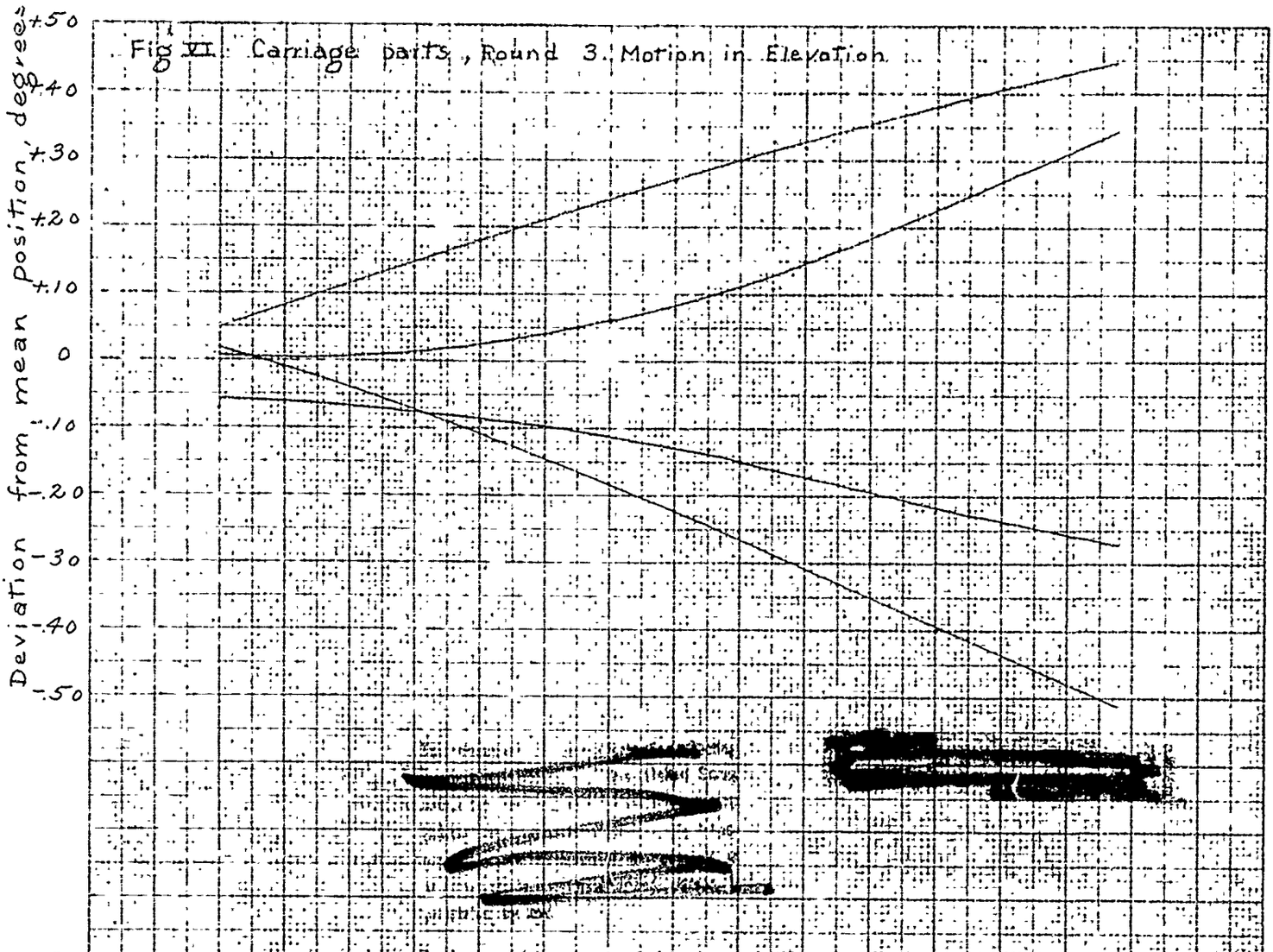
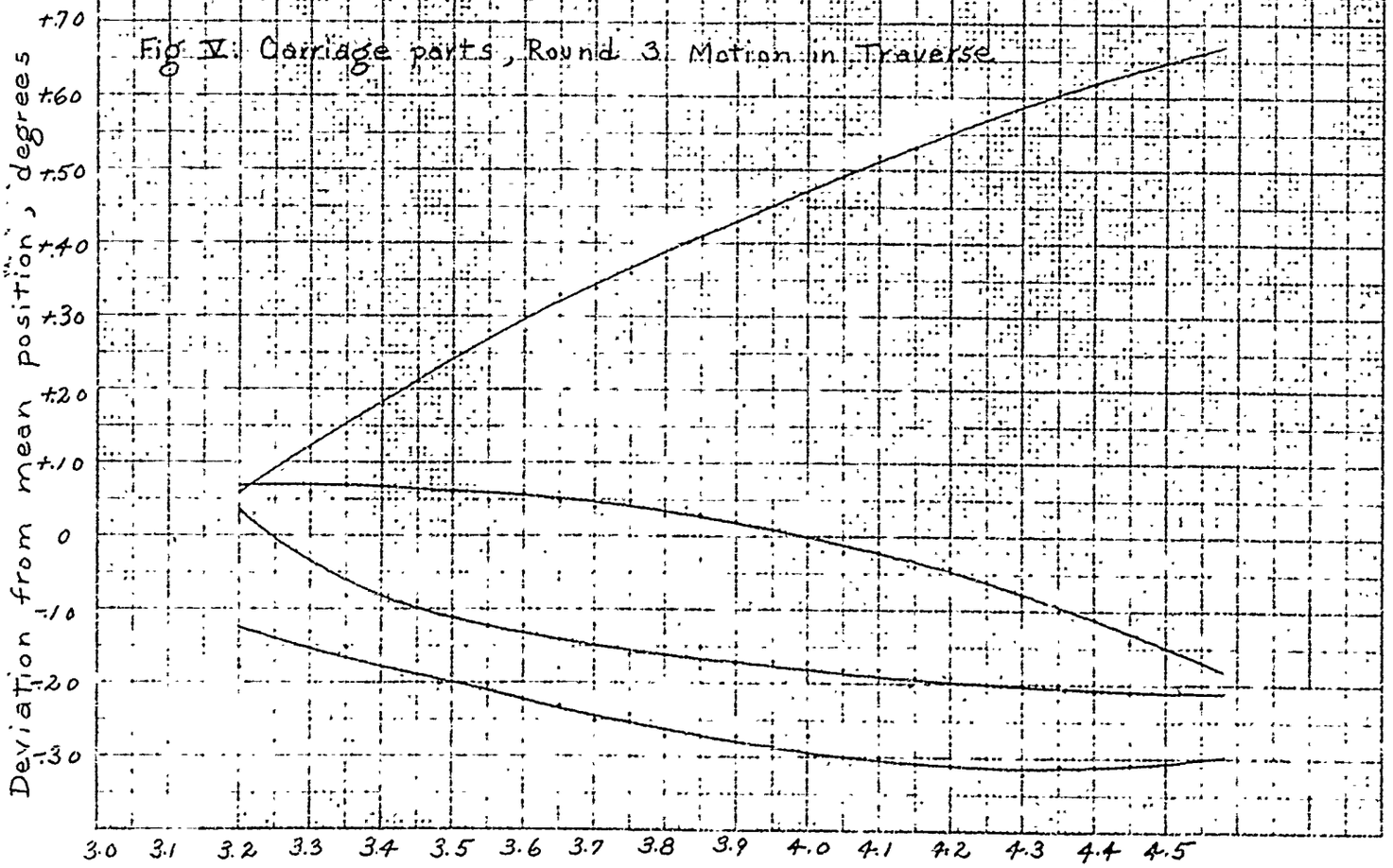


Fig V: Carriage parts, Round 3. Motion in Traverse



T-3

indicating a very satisfactory uniformity in the separation process. Measurement of the photographs yielded separation as a function of range only, since no timing device was in operation in connection with these cameras. For the relation between slant range and time, a numerical integration was made of curve a of Fig. I. This appears in Fig. VII, and is the basis of the time scale shown in Fig. IV. No special treatment was carried through for round #3.

Curve C of Fig. I was then plotted to fulfill the following conditions:

(1) Separation begins at 1.15 sec, when common velocity is 1526 ft/sec.

(2) Separation at 1.75 sec is 63 ft. This fixes the area lying to the left of the ordinate 1.75 and between curves a and c of Fig. I.

(3) Deceleration varies as velocity squared.

The curve determined by these conditions corresponds to an initial deceleration of the bird of 5.2 "g", or to a drag coefficient of 0.49. This must be regarded as uncertain by at least 10% or 15%.

A maximum deceleration of about 6 "g" was indicated by the most successful of the three Princeton sondes (reference 3). The one APL sonde record (reference 4), covering a very brief time interval just at the end of burning showed a rising deceleration; and at the end of the record the value was 6 "g" and apparently still rising. This agreement among the two sondes and curve c of Fig. I, is satisfactory, considering the quality of the measurements. The value 0.5 is therefore submitted as the drag coefficient of the bird, with an estimated probable error of 15%.

This result is in satisfactory agreement with existing data, from which the following calculation has been made:

Nose drag (reference 6)	0.16
Base drag (3/4 of value in ref. 6, allowing for duct exit area)	0.135
Skin drag, using coefficient .0025 (ref. 7) referred to lateral area	0.212
Total, referred to frontal area	0.51

[redacted]

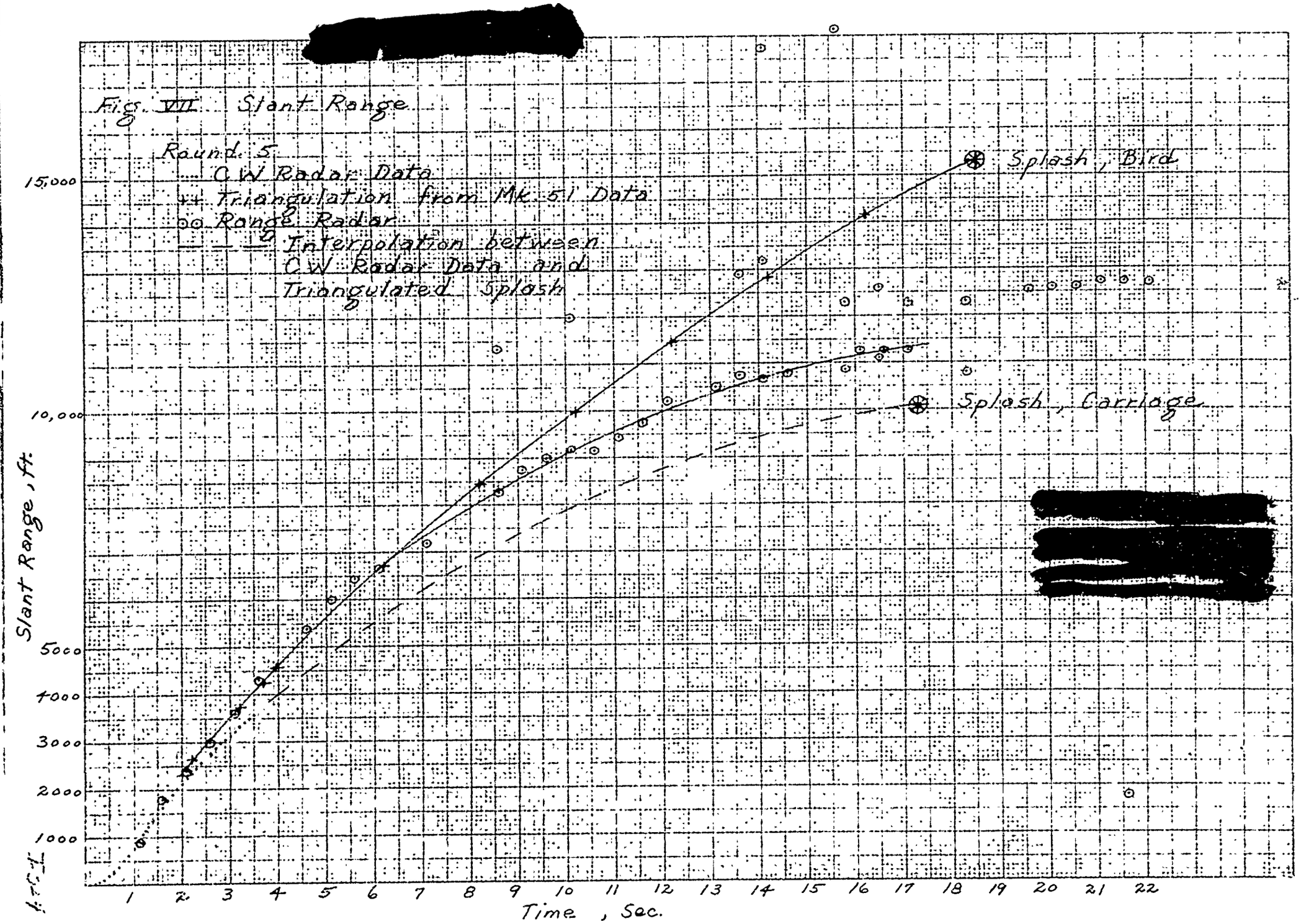

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Fig. VII Slant Range
Round 5
C W Radar Data
+ Triangulation from MK 51 Data
oo Range Radar
Interpolation between
C W Radar Data and
Triangulated Splash
Splash, Bird
Splash, Carriage
[redacted]
15,000
10,000
5000
4000
3000
2000
1000
Slant Range, ft.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
Time, Sec.

OVERALL TRAJECTORY. -- Figs. VII and VIII show the flight of round 5 and represent the best trajectory data secured. All data from other rounds are, however, in substantial agreement. The Mark 26 radar record is poor photographically. Evidently, as read, it contains a systematic error and refers to the launching carriage rather than to the bird. Tracking data from South and Central Stations were combined by triangulation. The South Station camera record on the bird was fairly complete, but that from Central covered only the first 4 seconds and the final splashes. Leveling of the two tracking stands was not adequately completed at the time of the test, and consequently the recorded elevations required empirical corrections of the order of 1°. Hence, the trajectory is not determined with high accuracy, but is probably known well within 5% at all points.

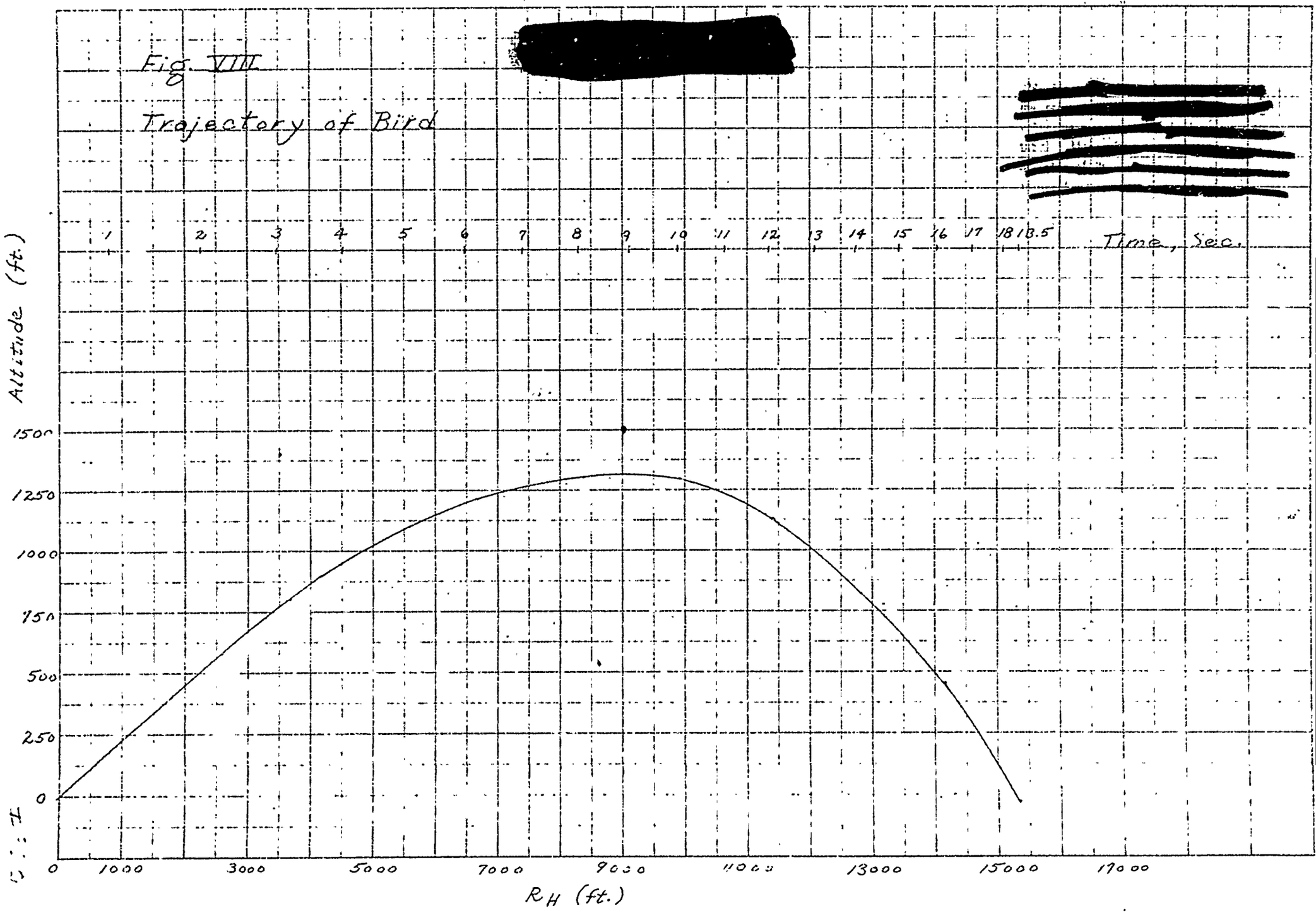
Fig. IX shows the positions of splashes, marking points of fall for both the bird and the carriage. The extreme dispersion in flight of the bird is about ± 1° azimuth and ± 500 ft in range. The carriages also fell pretty well together, except for #3, which broke apart.

The observed range of 5000 yd for the bird is in at least rough agreement with the determined supersonic drag coefficient 0.5. Inspection of ranges for Army howitzer projectiles of ballistic coefficients 4.4, 2.1, and 1.9 (relative to the G2 retardation function) led to a rough estimate of 1.2 as the ballistic coefficient corresponding to the range of the bird. For comparison, a ballistic coefficient 1.11 corresponds to the drag coefficient 0.5.

Velocity along the trajectory is indicated by Fig. VIII. The accuracy, however, is limited and permits not more than one deceleration to be stated as an average for the subsonic region. This is close to one "g" and leads to average drag coefficient of 0.4 for the velocity region between 950 ft/sec and 540 ft/sec, the estimated striking velocity.

Fig. VIII

Trajectory of Bird



REFERENCES

1. APL internal memorandum CM-15 (Goss to Roberts), "Results of First Tests of Model Athodyds at Island Beach." February 20, 1945.

2. Preliminary Report, "Doppler Recording of Ram Jet Test Model Velocities at Barnegat Bay", From Ballistic Research Laboratory, Aberdeen Proving Ground; transmitted to APL by letter (APG(s) 413.6/6) March 2, 1945.

3. Princeton University, Monthly Progress Report, NOrd-7920 PRN-2, March 14, 1945.

4. Internal memorandum CM-24 (Tetel to Goss), "Initial Accelerometer Trial."

5. Internal memorandum CM-17 (Peacock and Faulkner to Petersen), "British HVAR for Launching Test Models." March 1, 1945.

6. Internal Memorandum CM-7 (Rudnick to Goss), "Thrust and Drag Coefficients." February 6, 1945.

7. Von Karman and Moore, "Resistance of Slender Bodies Moving with Supersonic Velocities with Special References to Projectiles." ASME Trans. 54, p 303 (1932).

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APPENDIX I

Numerical Summary

Test was conducted at Island Beach, N. J. on February 16 and 18, 1945.

Round 1 at 5:16 P.M. (2/16) containing Princeton sonde.
Round 2 at 6:36 P.M. (2/16) containing APL sonde.
Round 3 at 3:50 P.M. (2/18) containing APL sonde.
Round 4 at 4:26 P.M. (2/18) containing Princeton sonde.
Round 5 at 5:00 P.M. (2/18) containing Princeton sonde.

Atmospheric Conditions (at Lakehurst, N. J.):

Feb. 16, 4:30 P.M. Temp. 49°F, Rel. Hum. 39%, Bar. 29.86".
Feb. 18, 4:30 P.M. Temp. 31°F, Rel. Hum. 42%, Bar. 30.07".

Weights:

Bird	55 lbs.
Launching carriage after burning	290 lbs.
Propellant	96 lbs.
Total assembly at launching	441 lbs.

Dimensions:

	Bird	Carriage
Overall length	9'7"	4'10"
Transverse	6.14" diameter	18.5" between launching rails
Number of fins	4	8
Total fin area	72 in.^{2}	540 in.^{2}

Launching (based on CW data, rounds 3 to 5):

Maximum velocity 1530 ft/sec ± 6% - 3% was reached at 1.1 sec.
Maximum acceleration....50 "g"
Average acceleration....43 "g"
Separation between bird and carriage complete at 1.15 sec.

Duration of supersonic flight (measured from end of burning at 1.1 sec.):

Bird.. ..... 4 sec (estimated).
Carriage, varied..1.1 sec (max.) to .7 sec.

Drag of Bird:

Velocity range, ft/sec,	1526 to 1420	950 to 540
Drag Coefficient, (force/area x $\frac{1}{2}\rho V^2$)	.5 ± 15%	.4
Deceleration Coefficient, (deceleration/V^2), ft.$^{-1}$ x 10^5,	7.4	6

Drag of Carriage:

Velocity, ft/sec,	1450	1300	1100	900
Mach number	1.33	1.19	1.01	.825
Deceleration, "g"	18.7	13.8	7.9	6.3
Drag force, lbs.	5420	4000	2290	1330
Drag coefficient referred to $13\frac{1}{2}$" square area, circumscribing four motor tubes,	1.62	1.49	1.19	1.42
Deceleration coefficient, ft.$^{-1}$ x 10^5, corrected to 59°F, 14.7 psi,	26.9	24.8	19.8	23.4

Trajectories:

	Round	Bird	Carriage
Ranges, ft	1	-	10,000
	2	-	9,575
	3	15,320	3,050
	4	16,415	9,435
	5	15,430	9,580 and 10,310.

Deflections from mean line of flight of bird, which lies 32°31' east of southward direction of road:

Round	Bird	Carriage
1	-	1°35' L
2	-	10' L
3	-	scattered
4	50' L	1°25' L
5	50' R	30' R

	Round	Bird	Carriage
Flight Times, sec,	3	-	14
	4	20.2	17.8
	5	18.5	17.3, 18.4

Approximate data for bird, round #5:

Maximum ordinate	1320 ft.
At horizontal range-	9000 ft.
and time	9 sec.
Angle of fall	24.5°
Striking velocity	540 ft/sec.

APPENDIX II

Check List of Field Data

Round	1	2	3	4	5
Central tracking,					
Flight	-	-	b	b	b
Splashes	-	-	b	a	a
South tracking					
Flight	-	-	c	b	a
Splashes	-	-	c	c	a
K-25 cameras	a	a	a	a	a
Radar					
CW	-	-	a	a	a
Mark 26	-	-	c	b	b
Deceleration sondes	c	c	c	b	b
Alidade bearings on splashes	a	a	a	a	a
Stopwatch times of flight	-	b	b	b	b

a - indicates data on which chief reliance was placed.

b - indicates less complete or less accurate data, used chiefly for confirmation.

c - indicates no useful record.

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ABSTRACT

The launching of an athodyd called "BIRD" Model 1D, with four 5-inch HVAR rocket motors is described. The speed exceeded 1500 ft/sec and the drag coefficient was found to be 0.5. The rocket was launched with the carriage from a 30-ft ramp of 15° elevation. One motor dropped off before 3 sec and the remaining three just after 3 sec. The total weight was 441 lb. The duration of supersonic flight measured from end of burning at 1.1 sec was estimated as 4 sec for the "BIRD" and 1.1 to 7 sec for the carriage.